Original article

A constructivist mobile learning environment supported by a wireless handheld network

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Abstract There is a need to incorporate constructivist environments in the pedagogical practice. A constructivist learning environment allows students to build up their own knowledge (based on previous one) while working jointly among them in a reflexive process directed by the teacher. Wireless interconnected handhelds can introduce a space that favours constructivism and collaboration in order to achieve creation of new knowledge. We have developed a constructivist learning environment supported by handhelds, for the teaching of reading for first graders. This environment was compared to an equivalent constructivist environment without technological support, obtaining significant different learning results.

Keywords collaboration, constructivist, handhelds, mobile computer-supported collaborative learning, primary, qualitative, quantitative, school

Introduction

Pervasive computing is progressively coping all niches of human actions including education. Handhelds are the main instrument we have in this direction. These are being used from elementary to university students, who may receive wireless information anytime, anywhere (Roach 2002). Handhelds are attractive since they are low cost; are portable permitting easily its use in the classroom or any other place, avoiding the need for children to go to a lab for their use; are wireless, allowing information access without being tied up to a fixed connection within a determined physical space permitting a face-to-face relation of the users; and have a sense of belonging since it is of a personal use during the activity.

Handhelds support constructivist educational activities through collaborative groups (Dede & Sprague 1999), increasing motivation, promoting interactive learning, developing cognitive skills (ordering, evaluating, synthesizing), and facilitating the control of the learning process and its relationship with the real world. (Valdez *et al*. 2000). Rochelle (2003) reports that it has been shown that both students and teachers respond favourably to handheld applications; however, its impact in the classroom has still to be proved. Our work shows how handhelds can be used as support tools for constructivist environments for 6–7-year-old children. These environments promote the development of communication and social skills encouraging dialogue and collaboration between members. As in Social Constructivism (Vygotsky 1978), each child acquires new knowledge based on the pieces that each group member contributes. Constructivism is only a general orientation with no defined procedures, which can be applicable to all educational contents and activities (Black *et al*. 1981).

Social Constructivism establishes a series of principles to be accomplished during the development of an educational activity (Newman *et al*. 1989). *Constructive* means that the students have to modify their current knowledge schemes to integrate new information and acquire new knowledge. *Active*

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indicates that a total student participation is expected. *Significant* refers that learning has to be with a meaning, built from the conceptual structure the student already has. *Based on consultation* points out that the child has to formulate his/her own questions, from multiple interpretations and learning expressions. *Reflexive* shows that the student has to mirror his/her own experience on other students, making them experts in their own learning. Finally, to be *Collaborative* indicates that the child learns from others by working together on the same objective, where each group member is a potential source of information (Roschelle & Teasley 1995). We show how these principles are supported by wirelessly interconnected handhelds in the model described in the next section, so that first graders can build up their knowledge as a group.

Research on collaborative learning (Johnson & Johnson 1999; Mandryk *et al*. 2001) and constructivist learning environments (Clements & Michael 1990) has shown that children see their classmates as a source of knowledge and help, rather than as a competition; the development of common values, social skills, and team work on a shared objective is encouraged, strengthening the children's self-esteem; children enjoy and learn more by being active participants of their learning rather than passive listeners; child education works better by concentrating on thought and understanding, instead of memorization; finally, children learn to collaborate and negotiate with their classmates, articulating ideas with the others.

According to Dillenbourg (1999), for an educational collaborative activity to be successful in the establishment of social interactions, the following factors are required: (a) a well-defined objective; (b) an activity regulation monitor, through rules and roles (Section 3.2); (c) a defined domain, i.e. number of group members, criteria for the group composition, and specification of the technological mediation; and (d) an adequate environment for the educational context.

A model to apply handhelds in constructivist learning environments

We have developed a model for constructivist learning environments based on face-to-face collaboration. The model is found on social constructivism principles (see the previous section): constructive, active, significant, reflexive, collaborative and based on consultation.

Handhelds support the *constructive* principle by providing each child with a share of the necessary information to accomplish the educative activity goal. Children must gather the available information and build up their answers based on the knowledge that each one contributes. The handhelds also give the students room for testing the different answers they give. By providing mechanisms that guarantee all students' participation in answer construction as well as decision-making, handhelds support the *active* principle. The *significant* principle is achieved by defining the educational objective and the activity with concepts known by the children and within their interest. The activity must encourage the necessary feedback for the children to formulate their questions; in this way an environment *based on consultation* arises. On the other hand, handhelds only act as support tools, without hindering the *reflexive* communication among children. Finally, the educational environment uses wireless communication between handhelds to support face-to-face *collaborative* work. The handhelds' properties permit to mediate among the students interactivity, positive interdependence and negotiation, and allow to establish social interaction needed in all collaborative activities (Dillenbourg 1999; Johnson & Johnson 1999).

Children first establish a face-to-face social relationships, i.e. the social network. Afterwards, the wirelessly interconnected handhelds provide the technological network that supplies the students the information resources and activity group information. The technological network serves as a scaffold for the social network, obtaining a collaborative learning activity supported by mobile computer technology, i.e. mobile computer-supported collaborative learning (MCSCL) (Zurita *et al*. 2003). During an MCSCL activity the children carry out individual and group tasks, according to the activity rules and roles. The technological network supports rules and roles to regulate their social interactions (Zurita & Nussbaum 2004).

A simple constructivist educational environment

An educational learning objective

A first-grade educational aim is the independent and comprehensive reading of brief texts, where all the letters of the alphabet and different types of syllables can be found. Up to around 1970 reading was taught

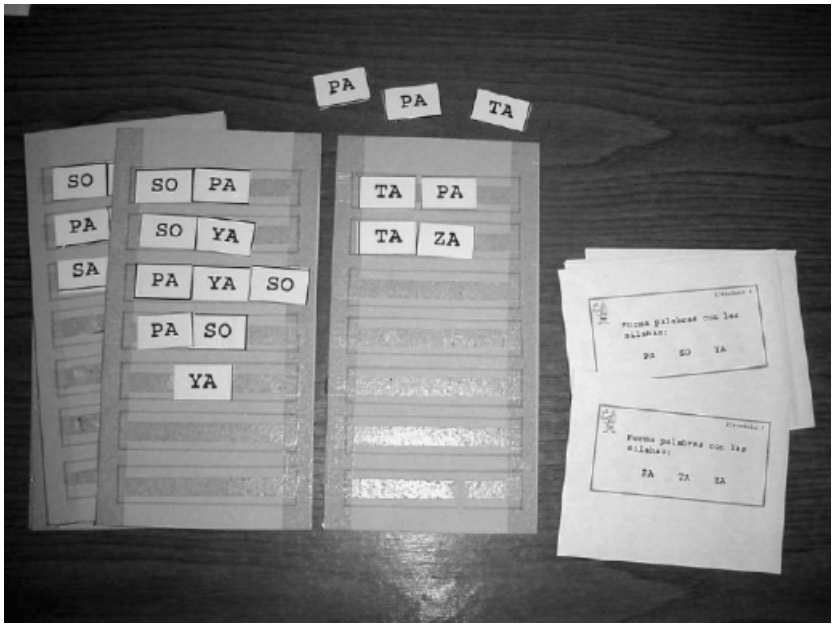

Fig. 1 Syllable-CL activity materials to construct words of one, two or three syllables in a three-member group.

by learning to pronounce the alphabet and by syllabic methods (NB1 – Nivel Basico 1 2003). Sixty per cent of the students had problems in reaching reading comprehension. Then a holistic approach based on social constructivism was developed. It deals with the students immersion in authentic texts, whose length and complexity are progressively graduated, without the need for further study of the code (letters, syllables, and words), Milicic (2000). However, not all the children could learn with this method (NB1 – Nivel Básico 1 2003). Today there is a trend to integrate methods. We implemented the syllabic method integrating to it a constructive practice. The educational goal was to recognize as many words in Spanish, from three given syllables, Milicic (2000). Children were randomly grouped in three, where each had one syllable. (A group size of three has shown to work best, Dillenbourg 1999.) They had to find out how to combine the syllables to build words that are known to them. (In Spanish, from a set of syllables usually a set of different words can be built). One environment was implemented, without technological support (Syllable-CL), and the other with the support of wireless interconnected handhelds (Syllable-MCSCL). Both learning environments were designed to be as close as possible, making the best possible use of each technology, to be able to compare the children' performance.

Description of the Syllable-CL activity and the learning environment

Each child of the three-member group takes out a token with a syllable from an envelope. The envelope contains tokens of three different syllables, placed to form one-, two-, and three-syllable words (Fig. 1) The child shows and/or tells the obtained syllable to the other group members. Working all three together, since each has a piece of the possible word, they have to identify and construct the correct words that can be formed. Once they agree on a word, the child who has the token with the first syllable of the word begins to construct the word by placing the token on a board. The rest must place their tokens in sequence according to the word to be constructed. If a child has a syllable that is not part of the word, then she/he will not place it on the board. Once a word is constructed, a second envelop with the same set of words is given repeating the cycle until the children can not build more words or no more envelops are available since the possible combinations are exhausted. The board will contain all the words constructed with the three syllables.

Afterwards, a new set of syllables is given to the children in new envelopes and with a new board to construct the words, repeating the previous procedure.

Fig. 2 On Syllable-MCSCL, the handhelds' interfaces show the syllables that Miguel (a, 'si'), Gustavo (b, 'la'), and Rodrigo (c, 'ba') should use to construct words. In order to construct the word 'silaba' ('syllable'), Miguel must choose his cloud button with the syllable 'si' (d), which is shown on Rodrigo's and Gustavo's hand-helds (e). After Gustavo and Rodrigo have chosen their syllables, respectively, the word is constructed (see f for Gustavo). If they all agree on the constructed word, and this is correct, all the hand-helds add the obtained score (g for Miguel), and ask for confirmation in order to continue constructing more words (h for Rodrigo). The words that have been constructed can be displayed (j), by activating the booklet button (see i).

Description of the Syllable-MCSCL activity and the learning environment

The Syllable-MCSCL activity presents eight identifiable elements:

Identification of the collaborative group. On the upper right part of the handhelds, an icon identifies the members of the same group (a sun on Fig. 2), allowing differentiation among groups.

Each child's individual information: one syllable. Each child has one syllable in his handheld (for example, 'si' (sy)[1] for Miguel, Fig. 2a, 'la' ('lla') for Gustavo, Fig. 2b, and 'ba' ('ble') for Rodrigo, Fig. 2c), making it possible to construct words when combined.

A space for each child's knowledge to be share with others. Each child must read and inform the rest of the members on the syllable he or she has, so that they can construct correct words as a group. The word must be constructed with the rest of the children through social interaction, agreements, and negotiations.

A space for constructing in turns, i.e. sequentially, according to the word. In order to construct a word with the handhelds, the cloud button that contains the syllable must be pressed orderly (to construct the word 'silaba' ('syllable'), Miguel, Fig. 2a must press his cloud with the syllable 'si' ('sy'), then Gustavo presses the syllable 'la' ('lla'), and finally Rodrigo presses syllable 'ba' ('ble'). If this order is not preserved another word comes out.

A common view for all the children. The word is formed simultaneously on each child screen, as everyone chooses their syllable. For example, Miguel in Fig. 2d chose his 'si' cloud, while Rodrigo's, Fig. 2e, and Gustavo's handheld show the same syllable that Miguel chose. The children who have already chosen their syllables must wait for the rest of the students (Miguel, Fig. 1d, has an 'espera a tus compañeros'

[1]The activity is in Spanish and we show its correspondence in English in parentheses.

('wait for classmate') text message, and the cloud button is blocked, with the 'si' syllable in another colour. When a given syllable is not part of the word the child has to click a button (bottom right) that indicates the syllable absence. For example, if the word 'si' ('yes') is built, then Gustavo, Fig. 2b, and Rodrigo, Fig. 2c, have to select their right bottom button.

Mechanisms of approval of the constructed answer to reach a consensus. Once a word is constructed the handhelds request a confirmation of the answer; a '¿estás de acuerdo?' ('do you agree?') text (Fig. 2f) and voice message is heard. Two options are shown: 'si' ('yes') and 'no' (Fig. 2f for Gustavo, and similar views for Miguel and Rodrigo). The handhelds wait until everyone has chosen a common answer. If this is not achieved, a 'pónganse de acuerdo' ('agree on answer') text and voice message appear (Fig. 2i), inducing to an agreement and requesting information again (all the handhelds return to the state of Fig. 2f).

Evaluation of the answer and decision-making to construct more words. There are three options. First, that the word is correct and all the children agree with the 'si' (yes) button; the handhelds make a clapping sound, display the built word and the amount of words constructed so far (Fig. 2g shows Miguel with the word 'silaba' ('syllable') and the number 1, for being the first word to be constructed). Then, the handhelds ask '¿quieres seguir formando palabras?'('would you like to construct more words?'), offering the possibility of constructing other words with the same set of syllables, and show the 'si' and 'no' buttons again for the answer (Fig. 2h). If the children do not agree on an answer, as in the previous case, an agreement is induced. If they all consent with 'si', the handhelds return to their original state and show the same syllables so that a different word can be built. On the contrary, if the students concur on not constructing more words with the given syllables, the handhelds ask if they want a new set of syllables or finish the activity (Fig. 2h). Second, when the children agree on constructing an undefined word the handhelds make an alert sound and a text message indicates that the word does not exist and the handhelds return to the initial state with the same syllables (Figs. 2a, 2b and 2c). This feedback is only possible when a teacher is present or when the activity is implemented with technology, as in this case. And third, if all the students answer 'no' after constructing a word, i.e. they agree that the word they constructed is wrong and so want to abort it, the handhelds return to the initial state with the same syllables (Figs. 2a, 2b and 2c).

Registration of constructed words. After the first correct word has been constructed, a booklet button appears on the left bottom side of the handheld screen (Fig. 2i), which shows the previously constructed words when activated (Fig. 2j illustrates Miguel's handheld after activating the booklet button).

Method of evaluation

A controlled experiment was run to test the impact on learning of Syllable-MCSCL (Experimental Group) versus Syllable-CL (Control Group) for first-grade students.

Participants

The children were from a low-income public school of Santiago de Chile. They all had basic knowledge of syllables and words, and they had been in school for eight and a half months at the time the experiment began. Both the experimental and control group were formed by 12 seven-year-old children each; seven of them boys in the first one, and the same number of boys and girls in the second one. In both the experimental and control groups, children were randomly grouped in three, maintaining the members throughout the experiment.

Procedure

To assess the learning outcome, a written pre-test was performed at the beginning of the experiment by both the control and experimental groups. It was a 35-min individual assessment for measuring the children's previous knowledge of word-construction. It used the standard Chilean grading scale from 1 (no correct answers) to 7 (all answers correct). The test consisted in eight exercises. For each, three syllables were given and the child had to write down all the words she/he could build using one, two, or all three given syllables. The score for each exercise was obtained considering the word complexity and the amount of words that could be built, following the criteria of Milicic (2000).

To assess the accomplishment of the constructivist principles, observation instruments were applied; the

classes were filmed and an interview was applied to all the children a couple of days after the experiment concluded. To measure the effectiveness of the collaborative activity the following criteria were observed (Adams & Hamm 1996, Johnson & Johnson 1999): (a) individual responsibility, i.e. each member is responsible for his or her own work, role, and efforts to learn within the group; (b) mutual support, i.e. each member is also responsible to help and teach other members of the group, through the frequent exercise of social skills during group interactions; (c) positive interdependence, where the principal goal of the activity is the group goal, so success is therefore only achieved once all team members have reached their individual goal; and (d) face-to-face social interaction, where decision-making must involve discussion between the collaborators and the group's ability to efficiently exchange opinions and make compromises to build a consensus answer.

The experiment lasted for 4 weeks with daily activities, totalling 20 sessions. Both experimental and control groups were given the same set of activities. Since it was experimentally discovered that the Syllable-MCSCL group required 40% less time (on average) to complete the given assignment their sessions were shorter, i.e. 25-min sessions in the Syllable-CL group and 15-min sessions in the Syllable-MCSCL group. The first two sessions were slightly longer (30 min for Syllable-CL and 20 min for Syllable-MCSCL) to allow the children to get used to the activity and technology. By the 12th session, some Syllable-CL groups were achieving their goal in 20 min, and some Syllable-MCSCL groups were achieving their goal in 10 min. In both groups, the children occasionally required teacher assistance, primarily with word-understanding problems.

On the first day, the aim of the activity was explained to the children, and the rules and roles were outlined. In the Syllable-CL group, children were assigned to groups by the teacher and asked to sit at a specific table. In the Syllable-MCSCL group, the children's partners were listed on their screens, allowing them to move freely through the classroom to find their group members and sit where they wished.

In each session the students had to construct words with seven sets of syllables, of increasing complexity. At the beginning of the experiment, the sets were made of simple identifiable syllables, which became increasingly complex as the sessions went on. The children spent in the first sessions a high percentage of the time learning how to use the technology (Syllable-MCSCL) or materials (Syllable-CL). Later, when the children had to construct more complex words, they were already familiar with the technology and materials, and were still able to complete the activity in about the same amount of time. At the end of the 20-day experiment a post-test was performed using the same test that was given as pre-test. As in the pre-test, each child was given 35 minutes to complete the test.

Results

Quantitative results

Analysis of covariance was run to test the effect of the intervention. Pre-test scores, on the specific subject tested, were introduced as a covariant in order to control initial levels of ability. The pre-test scores of the control group had a mean of 2,132 with a standard deviation of 1,285, while the post-test scores had a mean of 2994 with a standard deviation of 1,699. The pre-test scores of the experimental group had a mean of 2204 with a standard deviation of 1547, while the post-test scores had a mean of 4503 with a standard deviation of 1506. The intervention had a significant effect on post-test ability on constructing words, controlling for pre-test ability. The comparison showed that there was a significant difference between the two groups ($F = 6.5$ with $P < 0.05$), with the experimental group performing better that the control group.

Qualitative results

Table 1 shows the characteristic issues observed for the constructivist principles for the experimental and control group on the first and last session.

In the Syllable-CL activity the children had problems when dealing with the syllable tokens and managing the envelopes they came in. The envelope management problem was totally solved with the handhelds, that directly showed each child a syllable. Therefore, Syllable-MCSCL offers an environment where there is no arguing over the dealing of syllables, and the cognitive effort is targeted to the construction of words. Likewise, managing all the Syllable-CL material was a tedious task to carry out, which was transparent for Syllable-MCSCL, since all the neces-

Table 1. Constructivist principles observed for the experimental and control group on the first and last session

Principle	Syllable-CL		Syllable-MCSCL	
	First session	Last session	First session	Last session
Constructive	The children were mainly preoccupied for the token distribution and its placing on the board. Few instances of knowledge building were observed.	The children achieved criteria for the token distribution and its placing on the board. Some instances of knowledge building were observed.	All the necessary information was transparently delivered by the handhelds. The children could build new words based on the ones they already knew.	The handheld support was optimal. The children could build new words, based on the ones they already knew, faster than in the first session.
Active	Several children did not participate in the activity because of: (1) lack of interest; (2) were relegated by their group mates.	More children did not participate for the same reasons observed in the first session. Lack of motivation is evident in an important percentage of the children.	Group mates encourage the children not engaged to participate since these have machines, which carry a token they need. Those children tried to be relegated used their machines as an armature to participate.	All children actively participate; none is relegated and all show interest. All demonstrate motivation and concern that the activity should continue in time.
Significant	The words to be constructed were all familiar to the children.	As in the first session, the words to be constructed were all familiar to the children. More words were formed than in the first session.	The words to be constructed were the same as in Syllable-CL. More words were formed than in Syllable-CL.	As in the first session, the words to be constructed were all familiar to the children. More words were formed than in the first session and faster.
Reflexive	Few instances of reflection on what was done were observed.	As in the first session, few instances of reflection on what was done were observed.	It can be observed as a reflection on the learning process in some groups.	More groups observe their learning process and invest time to comment their results.
Collaborative Individual responsibility	Each tried to solve the puzzle on his/her own.	Nothing changed from the first session, since the children tried to solve the puzzle on their own.	The children immediately discovered their role in the group due to the mediation of the handheld.	Each child contributes actively with his role to the group.
Mutual support	Almost no instances of support to the group mates can be observed.	A general absence of support to the group mates is observed.	Due to the handheld mediation a high degree of support to the group mates is observed.	As in the first session a high degree of support to the group mates is observed. The children show each other their screens and move the machines around to build the words.
Positive interdependence	Almost none of the children understand what teamwork means.	Few groups show teamwork. Almost all the children that work do it individually.	Due to the handheld mediation the children immediately understand that for achieving their goal they had to work as a group.	As in the first session, team work is always observed.
Face-to-face social interaction	Few instances of social interaction can be observed, mainly related to issues different from the problem to solve.	Almost no social interaction is observed.	Immediately the children establish social interactions to solve the given problems. Few instances were observed were group mates encourage verbally one of the members to actively participate.	Almost all the constructed words were the result of a group agreement and the contribution of all the members.

sary information was given through the handhelds. Frequently, in Syllable-CL, there were little or no discussions over a word to construct since one student imposed his or her personal point of view. In Syllable-MCSCL, the handhelds gave each child the possibility to decide how his/her syllable was used, in relation to the rest of the group, and then if the formed word was correct.

Interactivity and social interaction, provided by the handhelds, offered a simpler and straightforward working environment than the Syllable-CL, where the characteristics of the constructivist activity (constructive, active, reflexive, and collaborative) were observed more intensely. Handhelds provided features that cannot be introduced without technology: feedback on whether the formed word is correct, and a structured decision-making procedure.

Conclusions

This paper shows the learning benefits of a technology-based activity over a paper-based activity to construct words from syllables. In a month-long controlled experiment, children performing the activity supported with technology were observed to have significantly higher word construction test score improvements than subjects performing the paper-based activity. We obtained a statistically significant difference at a 95% level. The introduction of mobile computer devices allows a learning environment where technology manages the necessary data and mediates to allow the students to work collaboratively following the constructivist principles, with less teacher support for its application than in CL activities. The Syllable-MCSCL application takes advantage of mobility and portability, and provides support to face-to-face collaborative work that allow the establishment of social interactions.

We observed that the characteristics of constructivism (described in the first section) were achieved better in the Syllable-MCSCL environment than in the Syllable-CL environment. The children experience and knowledge, mutual feedback, and own and shared reflection allow them to build as a group their answer (constructive) and are encouraged to explain their finding, i.e. the word meanings (reflexive). The children contribute with their ideas and knowledge socially, interacting and negotiating possible suggestions (based on consultation). Finally, every child' contribution is shown to the other children within the group in a common space (significant, reflexive and collaborative).

Our experience can be generalized. The proposed model can be introduced with different aims and educative contents (Zurita *et al*. 2003; Zurita & Nussbaum 2004), and with children of different ages (Cortez *et al*. 2004). However, as indicated by Roschelle (2003), the impact on learning with mobile devices depends of the pedagogical practice and the models to introduce the technology at a larger scale.

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